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The IIT Fluid Dynamics Research Center is nearing completion on the construction of a flexible diagnostic wind tunnel. This national facility will become a center for research at the university level on active and passive flow management of turbulent, unsteady and three-dimensional aerodynamics at high subsonic speeds. This unique wind tunnel will fill a serious void between other current basis research facilities in this country, and its use will be open to university, government and industry scientists. The facility is designed to operate at velocities up to 500 ft/sec in a test section of 4 ft by 5 ft cross-section by 40 ft long. All operations of this facility, including optimum free-stream settings, unsteady flow operation, cooling of the tunnel air, the positioning and motion of aerodynamic models, the setting of streamwise pressure gradient as well as three-dimensional motions of traversing mechanisms and model positions, will be controlled by digital computers. In addition the computers used in processing of results will be connected to the national supercomputer network through a high speed link.

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SUMMARY:

The IIT Fluid Dynamics Research Center is nearing completion on the construction of a flexible diagnostic wind tunnel. This national facility will become a center for research at the university level on active and passive flow management of turbulent, unsteady and three-dimensional aerodynamics at high subsonic speeds. This unique wind tunnel will fill a serious void between other current basic research facilities in this country, and its use will be open to university, government and industry scientists. The facility is designed to operate at velocities up to 500 ft/sec in a test section of 4 ft by 5 ft cross-section by 40 ft long. The first 12 ft of the test section consists of interchangeable units which will allow installation of models or transducers without interrupting ongoing experiments. All operations of this facility, including optimum free-stream settings, unsteady flow operation, cooling of the tunnel air, the positioning and motion of aerodynamic models, the setting of streamwise pressure gradient as well as three-dimensional motions of traversing mechanisms and model positions, will be controlled by digital computers. The facility will be fully instrumented to do multi-sensor constant temperature anemometry, laser doppler anemometry, flow visualization, digital image acquisition of visualized flowfields, mean and unsteady pressure measurements as well as measurement of three components of force. Simultaneous acquisition of all transducer outputs will be done digitally with a parallel network of mini- and micro-computers, allowing both post-acquisition processing and real-time processing with closed loop control. In addition the computers used in processing of results will be connected to the national supercomputer network through a high speed link.

We are currently approaching the completion of the National Diagnostic Facility Wind Tunnel (NDF) at IIT; see Figure 1. The funding of this facility was initiated under a 1983 DOD University Research Instrumentation Program (AFOSR Grant 83-0339). In that proposal, we had conceptualized the direction and focus of a new facility which would satisfy the needs for quality research in the area of high-subsonic unsteady and three-dimensional aerodynamic problems. To satisfy this broad requirement, we had noted that this facility would be required to have very low turbulence levels, high subsonic speed potential, a long, large area test section, mechanisms for producing controlled mean unsteadiness, and complete computer control and high-speed data acquisition and processing capability. This facility was to be unique in that it would be the first of its type to employ all these capabilities, especially with high flow quality, and to be located within a group active in basic research <u>on a university campus</u>. Furthermore, it was intended to be a focus for Air Force laboratories, industry and other university researchers with similar interests in related areas. Clearly the nucleus of these collaborations would be the facility. Therefore, some review of its originally proposed and later expanded capabilities, which give direction to the special aspects of the design and to the final configuration, are in order.

In the original proposal we had intended the facility to have a velocity range up to 350 ft/sec in a constant area test section of 4 ft by 5ft cross-section by 40 ft long. This design would have used an 8ft diameter vane axial fan driven by a 1500 hp motor to overcome the estimated 17 in. of water in tunnel-circuit pressure drop. We intended to use a conventional tube-bundle heat exchanger to remove heat energy introduced into the air by viscous effects and fan inefficiencies. Although the facility would be designed to operate in a controlled unsteady free-stream, we did not propose to install the unsteady flow generators within the initial budgeted amounts.

This original design was modified in May, 1984 at the request of Major Michael Francis, the AFOSR contract monitor for this project at that time, in order that the facility be capable of a higher maximum velocity of between 420 and 500 ft/sec. The effects of this change were given in a Modified Budget Proposal submitted to AFOSR. This primarily involved the replacement of the propulsion system by a 9ft diameter vane axial fan and 2000 hp constant rpm motor, motor controller and magnetic clutch. All of the additional costs in the revised budget were directed at these items. Additionally we proposed to modify the test section design to allow pressure gradient control to reduce the static pressure rise around the circuit which now was becoming excessive at the higher design velocities. The subsequent impact of the high maximum velocity has resulted in other design changes since the Modified Budget Proposal. In particular, the added heating of the air produced at higher speeds resulted in changing the choice of a tube bundle heat exchanger which would produce too much pressure drop (almost 60 percent of the total pressure drop around the tunnel circuit). This required a new design approach which incorporated the air cooling with the turning vanes.

The addition of cooling-vanes in the turn downstream of the test section has prompted some changes in the design of the return leg of the tunnel upstream of the fan. These changes are significant because they impact the unsteady flow mechanism which is to be located in that leg. Also, the extra static loads produced by the mass of chilled water in the two sets of cooling-vanes has required considerably more extra floor stiffening than previously expected. We have estimated the extra dynamic loads produced when we would operate in the unsteady flow conditions and have appropriately strengthened the overall wind tunnel shell structure base and floor assembly.

In the spirit of minimizing pressure drop, we have also designed the turning vanes upstream of the test section to act as sound level attenuation devices. In this case they will be hollow and filled with varying thickness of sound absorbing foam. The high pressure side of the vanes is covered with an acoustically transparent high pressure drop sheet which also forms the trailing edge tab. Cavities within the vanes, as well as their overall spacing provide for a tuned response to a broad band of acoustic modes expected to be present inside the tunnel loop. Similar sound absorption is intended in the turn just upstream of the fan to provide the maximum amount of acoustic isolation to the test section.

In the past year, the motor, clutch and fan have been operated under manual control in order to perform surveys of velocity conditions and pressure drop in the diffuser sections upstream and downstream of the fan. The pressure drop readings have been used to correlate our estimates for the tunnel as well as to predict the air temperature rise and maximum test section velocity. The velocity surveys were important in certifying the quality of the flow field exiting from the fan and developing in the long diffuser section upstream of turn one. A provision had been left in the design of the cross-leg between turns one and two for the addition of a grid if the flow there had not been satisfactorily uniform.

In the settling chamber upstream of the contraction, we have selected a molded plastic honeycomb with 1/4 inch cell openings by four inches long. This was chosen over a comparably sized aluminum honeycomb because the plastic honeycomb can be made in smaller sizes which can be bonded together without a seam line to fill the needed 12.5 by 10 foot inside cross-section. The aluminum honeycomb could not be obtained in one piece to suit these dimensions, and noticable seams would occur where smaller sections were joined. Downstream of the honeycomb, a series of six low solidity screens reduce the scales of turbulence so that at the entrance of the test section a turbulence intensity of 0.005 percent is expected.

The wiring of the fan, motor, clutch, fan-vane hydraulic unit and other related hardware was completed last summer. This also included automatic "fail-safe" circuits which are designed to shut down the motor in the event of an out of design condition such as excessive vibration, bearing temperature, loss of hydraulic pressure etc. After approximately 60 hours of operation, we have experienced no problems with any of these components or unexpected shut-down. In the initial wiring, all the provisions for computer feedback and control were made. We currently are making the low-power connections to the Masscomp computer parallel inputs/outputs and A/D and D/A channels to turn full operation of the tunnel to computer control.

As disscussed earlier, in order to satisfy the broad goals set for the facility, a number of new design concepts were needed. Many of these were motivated by the need to minimize the static pressure losses around the tunnel loop, which was necessary to offset those produced by the high tunnel velocities and long test section. A key aspect of that design is the manner in which heat energy, produced by fan inefficiencies at a rate of approximately 6 million Btu/hr at the highest velocity setting, is removed from recirculating tunnel air stream. Of course, removing the added heat to maintain a constant air temperature is central to the use of resistance temperature velocity transducers. The common approach would be to place a standard tube bundle heat exchanger into one of the low speed legs of the wind tunnel. In our design, this approach would increase the total static pressure loss for the tunnel by approximately 70 percent (an increase from 18 to 29 inches of water), and significantly lower the maximum velocity (from 550 to 433 ft/s).

To bypass this problem, we had developed and implemented for the first time, the use of corner turning vanes which also act as heat transfer elements. The feasibility of this approach was first determined in the M.S. Thesis by Codner (1986). There he developed a computer model to predict the heat transfer rates for different cooling-vane geometries and performed model experiments to benchmark these. In the model experiments the effect of different geometries on the fluid mechanic properties including static pressure losses, production of turbulence scales and sensitivity to misallignment were also documented. These results were then used to extrapolate the model results to the full scale application. In the NDF tunnel, in order to have sufficient surface area, two of the 90 degree turns will contain cooling turning vanes. These are turn 1, just downstream of the fan in the tunnel schematic in Figure 1, and turn 3, just downstream of the test section. A three dimensional representation of turn 3 is shown in Figure 2. The combined use of these two turns is capable of removing 8 million Btu/hr at an air/chilled-water temperature overheat of 100°F .

To provide this cooling capacity, a total of 60 vanes, each having a 35 inch chord and lengths of 10.0 (turn 1) or 7.5 feet (turn 3) were required for the tunnel. Manufacture of these presented some interesting problems. We ultimately decided to have these extruded from aluminum in three parts. An assembly drawing for these is shown in Figure 3. As seen in the cross section at the top of that figure, the interior of the vanes are hollow and partitioned lengthwise into 8 sections. Cooling is to be provided by chilled water which flows through these passages in an arrangement which flows counter to the tunnel air. This design was deemed unique enough that it was awarded the first prize in the 1988 International Aluminum Extrusion Design Competition, which is sponsored by The Aluminum Association. The cooling vanes and wind tunnel turn sections are now being constructed.

What is needed to make the cooling vane system operational is a source of chilled water. In order to achieve the needed air/chill-water overheat values and to limit the maximum operating air temperature, we require chilled water at the lowest possible temperatures (less than 40°F at 800 gal/min). Based on a number of criteria which includes the ability to operate under a wide range of cooling loads dictated by the test section velocity, initial and operational costs, limited space, ease of maintainence, reliability and useful life, we have selected an ice-storage chilled water system. Figure 4 documents the required cooling load (in thermal tons equal to 12,000 Bru/hr/ton), as a function of test section speed. Using this as a basis we have sized an ice system which would give a total storage capacity of 1100 ton-hrs. Along with an 85 ton chiller to manufacture ice, this would allow continuous operation of the wind tunnel at speeds of up to 250 f/s, which is approximately 2.5 times those of common university wind tunnels, and two hours of operation at the maximum tunnel velocity of 550 f/s. When fully depleted the 85 ton chiller could make ice to bring it to its full capacity in 12 hours. This would typically be done overnight to benefit from reduced off-peak electric costs. In terms of an initial cost, an ice-storage system such as this costs more than a factor of two less than a 500 ton full-time chiller unit which would be needed to satisfy the peak cooling loads at the highest operating test section velocities. In addition, such a large capacity chiller would be much more expensive to operate, especially when considering that at the moderate speeds (approximately 200-300 f/s) where a majority of experiments will be performed, the cooling loads are significantly less (Figure 4).

A schematic of the ice-storage chill water system we propose to purchase is shown in Figure 5. The basic system would consist of an 85 ton reciprocating compressor, forced air evaporative condenser, refrigerant liquid feed equipment, refrigerant piping and vessels, an 1100 ton-hr capacity ice-on-coil style ice-storage unit, water piping and valving and microprocessor based control system. The chill water pump is an already existing item and would not be a part of the new equipment. The components that make up the basic unit are standard items which use established technology. Similar ice-storage systems have been installed in industrial plants and commercial buildings as chill water sources, often replacing older, larger and more expensive to operate full-time chiller systems. Because of the very basic components and simplicity of the system, it has an estimated long useful life. The compressor and pumps only require standard maintenance such as periodic lubrication. The ice-storage unit requires no maintenance. The evaporative condensor unit will have included an automated chemical treatment system which will impede the growth of organisms. Since all operations of the ice-chiller system, as well as the NDF wind tunnel, are controlled and monitored under computer direction, we will program in maintenance schedules based on manufacturer recommendations on operating hours and/or total ellapsed time. In addition, since we monitor by computer various test points in the system, we can detect off-peak performance operation which may indicate a need for maintenance which precludes pre-programmed maintenance schedules. We currently have these features built into the computer operation of the wind tunnel motor, magnetic clutch and vane-axial fan.

The installation of the ice-storage chill water system is expected to be completed 190 days from the date of order. A propsal was recently submitted to the DoD/DURIP to fund this system. Assuming a beginning of grant period of September 30, this system could be installed and operating with NDF by March 1989, only three months past the date we project for completion of the NDF wind tunnel loop. The purchase and installation of the ice-storage chill water system will impact the operation of the NDF wind tunnel by allowing a stable temperature environment needed for accurate velocity measurements made using hot-wire sensors. The first experiments proposed for the National Diagnostic Facility Wind Tunnel will involve high Reynolds number investigations of turbulent boundary layers, and separated flows with and without mean free-stream unsteadiness. These experiments will build on our experience and expertice which has already demonstrated in these areas and which is currently part of DoD funded research at IIT.

To provide the capability for these types of experiments in the 40 foot long NDFWT test section, we further intend to install a suspended boundary layer plate which will be instrumented with distributed pressure taps and removable measurement plugs. The plate will be constructed from polished stainless steel panels and segmented to allow rearward and forward facing step configurations. The ceiling of the NDF test section will be movable to provide full streamwise pressure gradient control. In one section, the ceiling will be more finely segmented for free-streamline control in the viscinity of models or wall steps as in the case of the separated flow experiments. All these motions will be directed under computer control. As with our other facilities a computer controlled motorized traversing mechanism will move sensors in three direction over the full 40ft length of the tunnel test section. All of these items including dedicated instrumentation for the facility have been appropriated in the DoD URI Center of Excellence Grant FY:86-90 (AFOSR F49620-86-C-0133).

With its completion, we believe that the National Diagnostic Facility Wind Tunnel can become immediately productive and yield results at near-flight Reynolds numbers which will aid in the design of next generation aircraft. Such basic information could otherwise not be obtained by another facility in this country.

National Diagnostic Facility

Illinois Institute of Technology

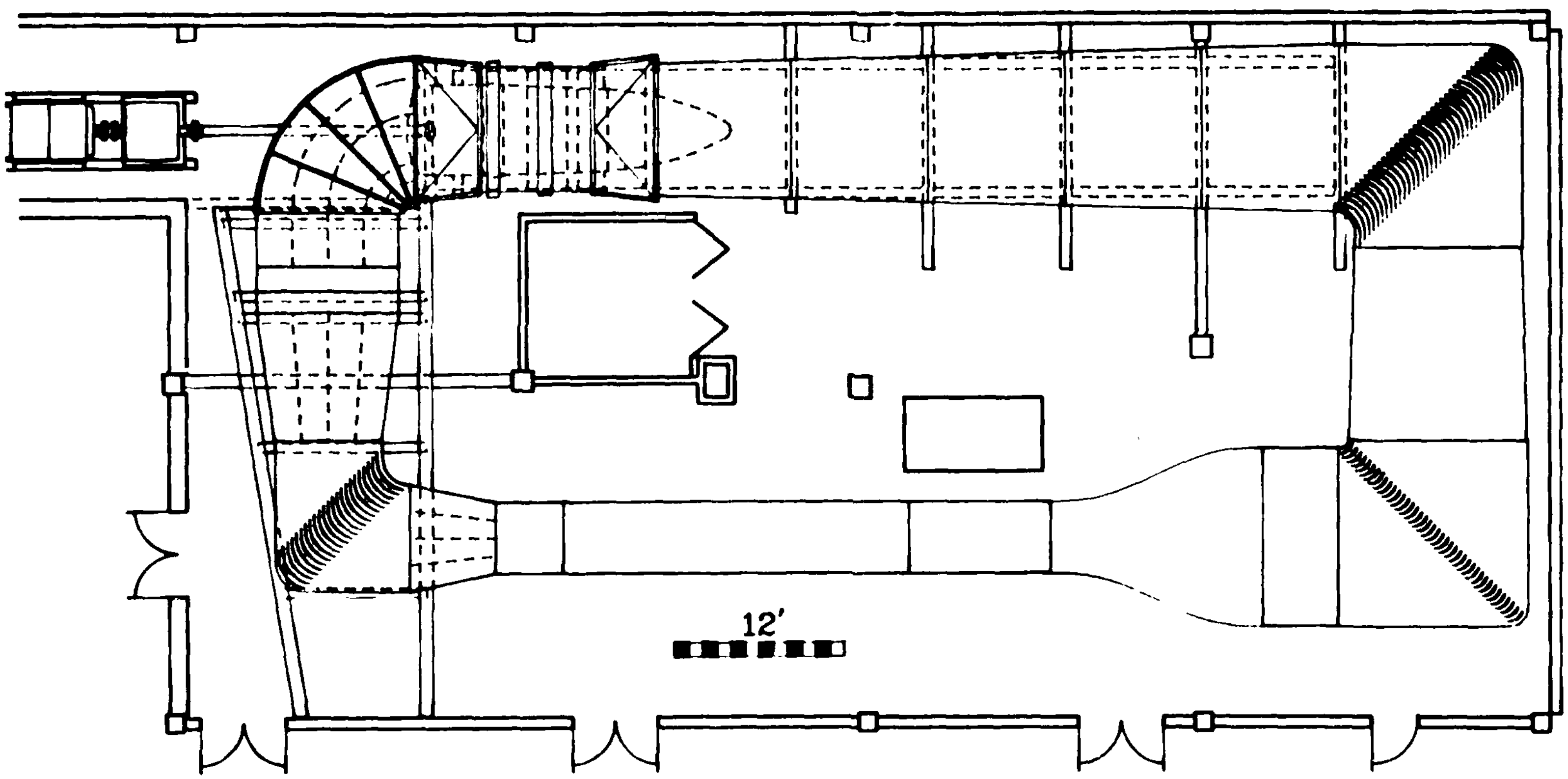

Figure 1. Plan view schematic of National Diagnostic Wind Tunnel.

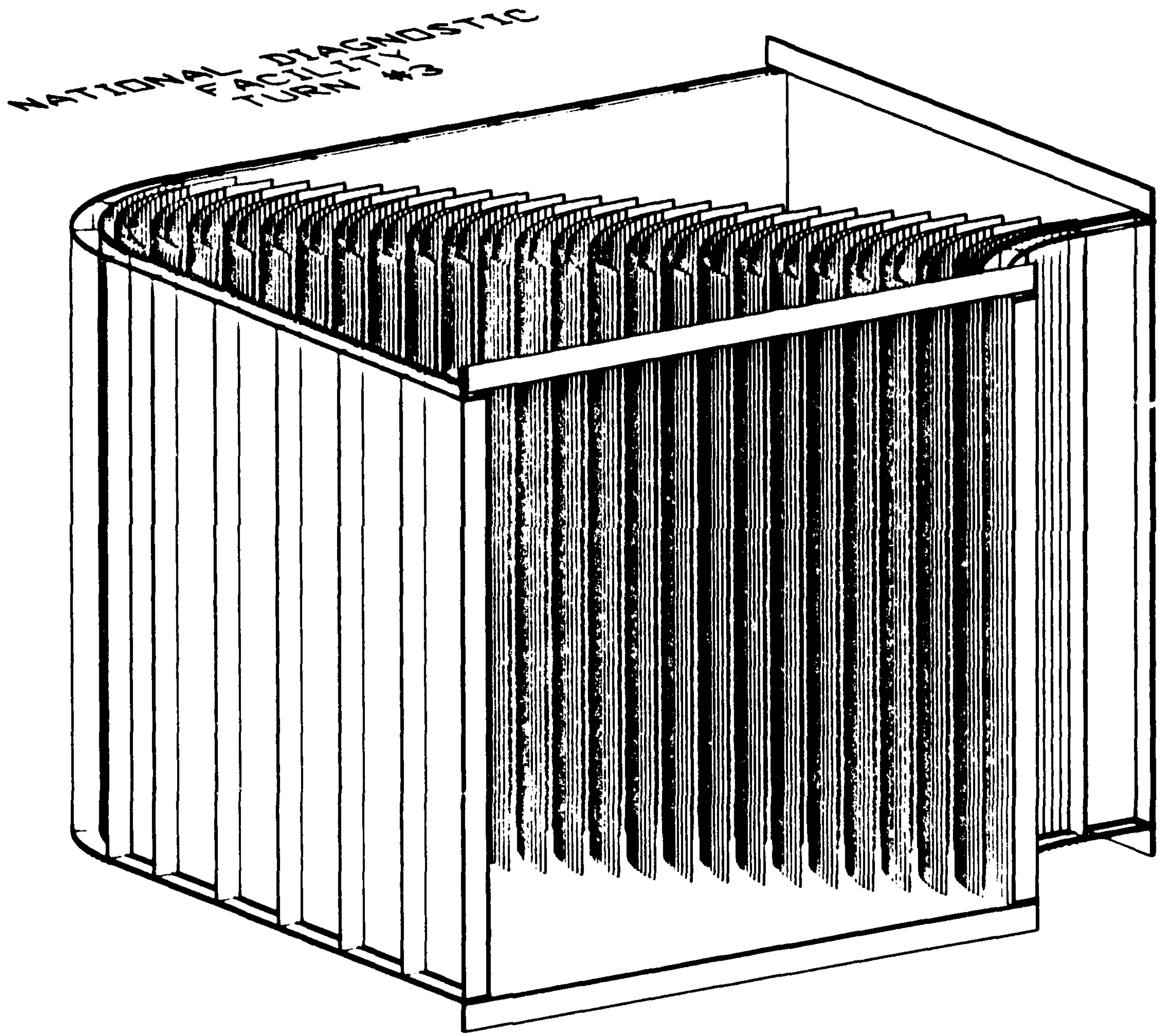

Figure 2. Representation of combined turning-vane/heat exchanger for turn 3 of NDF. Turn 1 has similar design.

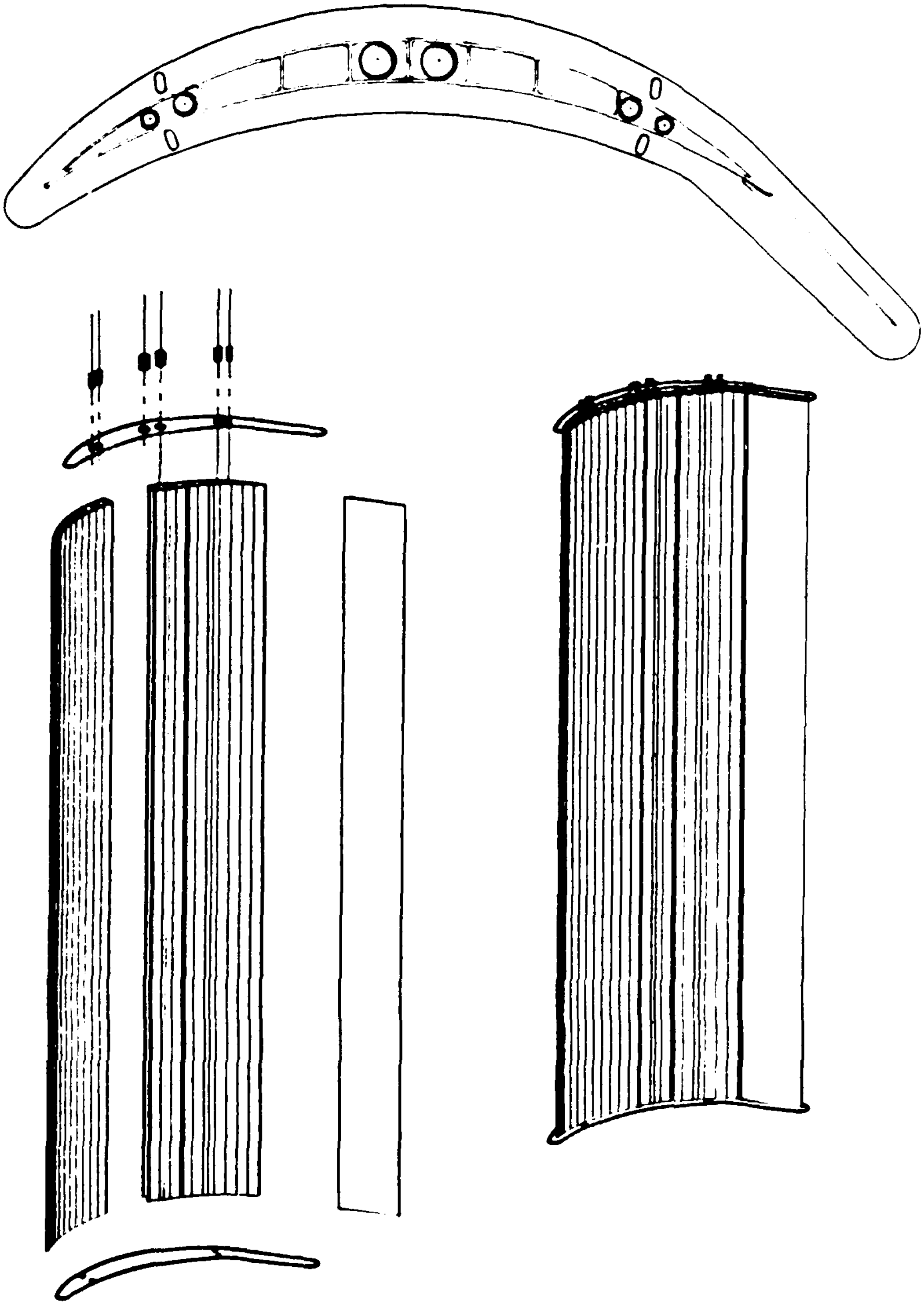

Figure 3. Drawing of single cooling-vane assembly with cross-section view showing internal vane partitions.

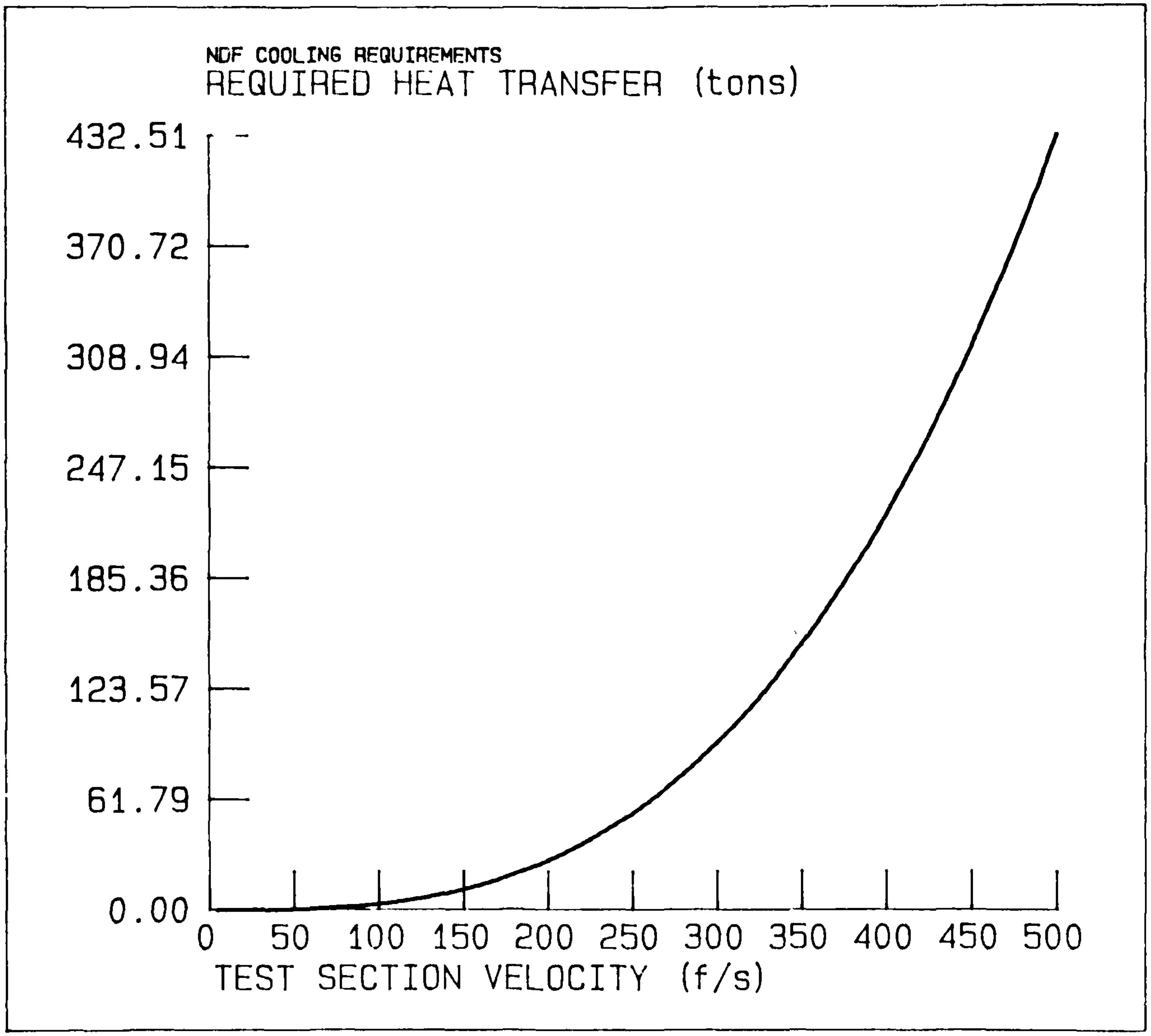

Figure 4. NDF cooling requirements as a function of test section velocity.

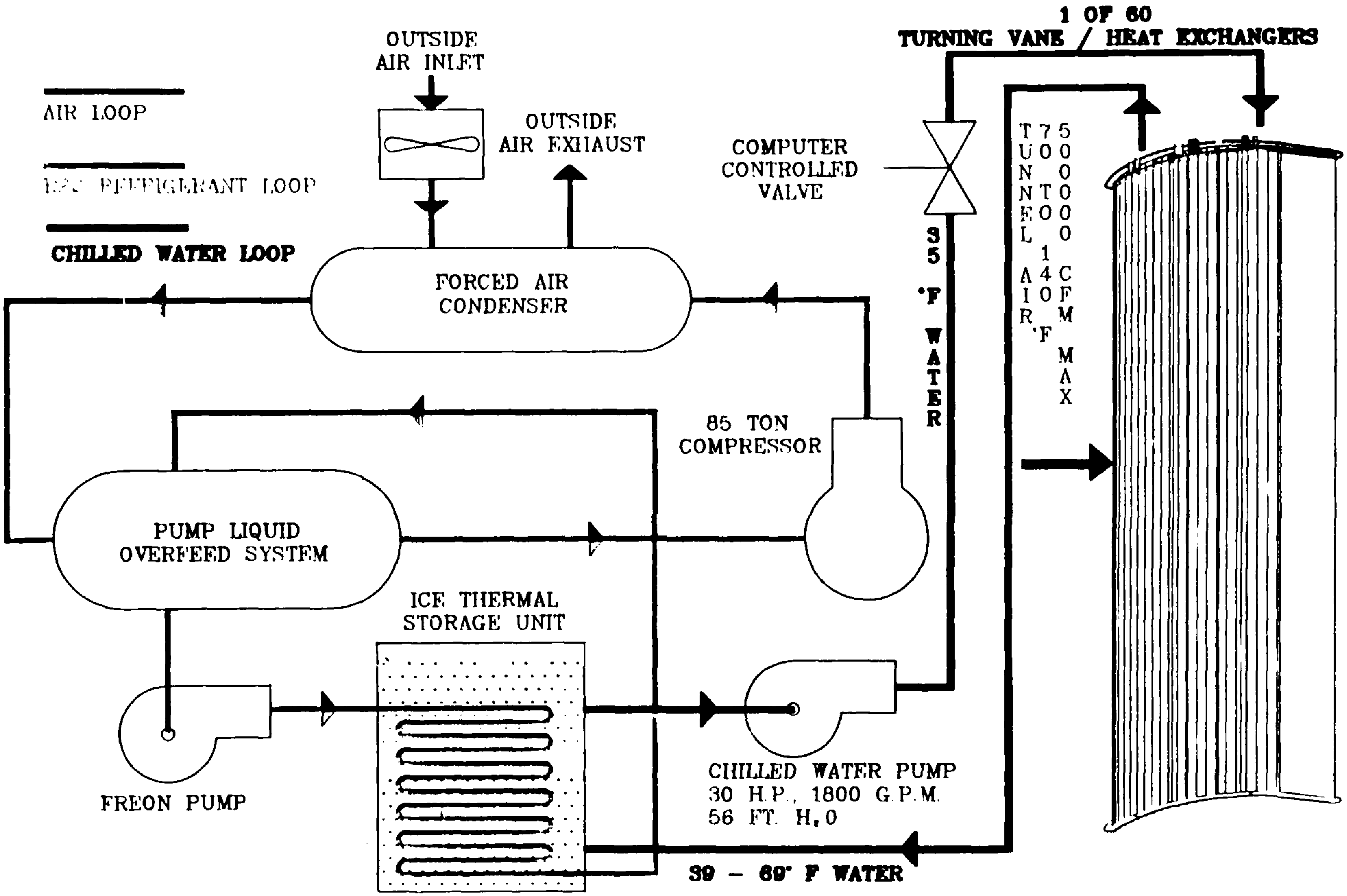

Figure 5. Schematic of ice-storage chilled water system for temperature control of NDF.